Using the Transparency tube in Minnesota's New Citizen Stream-Monitoring Program

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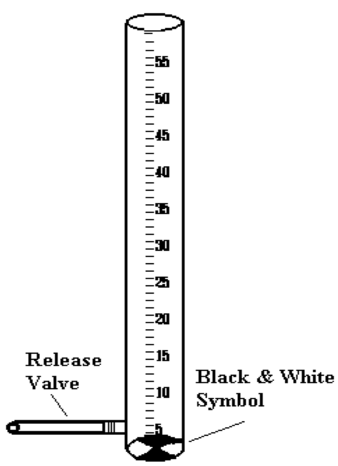
Minnesota offered a statewide Citizen Stream-Monitoring Program for the first time in 1998. The program centers on volunteer measurements of stream water clarity using the transparency tube, originally developed in Australia as a simple tool for monitoring stream water quality. Looking down into a tube filled with a stream water sample, water is released through a valve until the black and white symbol on the bottom is visible. The water depth when the symbol becomes visible is recorded in centimeters, which are marked on the side of the tube. During each stream visit, volunteers rank their stream for stage (Low, Normal, High), Appearance, and Recreational Suitability. In addition to weekly stream readings, volunteers track precipitation on a daily basis, and are asked to take more frequent stream readings following rain events when possible. Data collected by volunteers are permanently stored in the EPA's water quality database, STORET. Statistically significant relationships have been identified between stream transparency and turbidity, and transparency and Total Suspended Sediments (TSS). In the same way as Secchi transparency allows for the estimation of chlorophyll-a and total phosphorous, relationships among stream transparency, turbidity and TSS could provide a basis for citizens and the state to characterize the health of a stream by estimating these significant water quality parameters with a simple tool. Future work will focus on continued development of the volunteer program statewide, and further evaluation of relationships among transparency and other water quality parameters through studies currently being conducted on Minnesota rivers.

Background

The Minnesota Pollution Control Agency (MPCA) offered a pilot Citizen Stream-Monitoring Program (CSMP) for the first time during 1998. Volunteer stream-monitoring was not new to the state when the program began. Many school and community groups have been monitoring streams for a number of years. As volunteer stream-monitoring developed throughout Minnesota, the MPCA wanted to determine an effective way to contribute to the process. Toward this end, the agency initiated discussions in 1996 with people throughout the state who were involved in volunteer monitoring. Discussions focused on what was needed to enhance volunteer stream monitoring in Minnesota, and who would be most appropriate to address these needs. There was general agreement that to be successful, a statewide stream-monitoring program coordinated by the MPCA would have to be relatively simple and streamlined. As these discussions took place, agency staff in southeastern Minnesota worked with a number of local government, school, and citizen partners to test a new water-quality monitoring tool called the “transparency tube” (see box below).

A statewide coordinator was hired in March 1998 to launch a pilot Citizen Stream-Monitoring Program. Program goals were developed and the first volunteers were enrolled during summer 1998. These goals were based on experience gained during transparency monitoring trials conducted in southeastern Minnesota and the outcome of discussions about how the MPCA could enhance volunteer stream monitoring.

The Transparency tube



The transparency tube was developed in Australia as a tool for measuring stream water clarity, which serves as a basic indicator of water quality. The tube is 2 feet long x 1½-inch wide, made of clear plastic, and has a release valve at the bottom. A stopper inserted at one end of the tube is painted black and white, so that when you look down into the tube a distinct symbol is visible at the bottom. To measure water clarity, the tube is filled with water collected from a stream or river. Looking down into the tube, water is released through the valve until the black and white symbol is visible. The depth of the water when the symbol becomes visible is recorded in centimeters, which are marked on the side of the tube. If the symbol is visible when the tube is full, the transparency reading is “>60 centimeters.” A greater transparency reading in centimeters reflects higher water clarity.

Citizen Stream-Monitoring Program Goals:

- Collect valuable water-quality data by expanding statewide stream-monitoring network
- Provide a basic program for anyone interested in stream-monitoring
- Compliment existing citizen efforts
- Facilitate awareness of water-quality issues & promote *shared goals* and responsibility for protection

The Program at a Glance

The CSMP uses a collaborative approach to stream monitoring by partnering with citizen volunteers who live on or near a stream, and who are interested in water quality. Any person or group willing to devote a small amount of time and energy to conduct simple stream checks on a regular basis can participate in the CSMP. There is a one-time $20 fee to enroll in the program, which covers a portion of the cost of monitoring equipment provided to volunteers. Volunteers receive a transparency tube, rain gauge, data sheets, and instructions for taking measurements. Once a week from April to September (and following large rainfall events when possible) volunteers visit an established spot on a nearby stream and measure the following:

Measure	**Measurement tool**	**What it tells us**
Transparency	Transparency tube - clear, 60 cm-long tube with colored disk on the bottom	The amount of sediment, algae, & other materials suspended in the water
Precipitation (recorded daily)	Rain gauge	How rainfall events affect stream transparency, appearance, and stage
Stream stage	Visual estimate (Low, Normal, High) <u>or</u> Measurement from benchmark above stream	If changes in water level, which may occur during rainfall events, affect transparency & appearance
Appearance	Visual assessment of stream-water color	Potential causes of low transparency (e.g. sediment, algae, bog stain)
Recreational Suitability	Visual assessment on a scale of 1-5 (1=Very Good, 5=Very Poor)	The perceived suitability of a stream for fishing, swimming or boating

Volunteers submit data to the Pollution Control Agency at the end of each monitoring season. An annual report that summarizes data collected by volunteers statewide is compiled and sent to volunteers and other interested parties.

CSMP Measures

<u>Stream Water Transparency</u>

Transparency of water is affected by a number of factors. Both *dissolved* and *suspended* materials can influence water transparency. For most water bodies, the amount of solids suspended in the water is the most important factor: the more suspended materials, the lower the water transparency. In lakes, the majority of suspended solids are algae. In streams and rivers, soil particles (predominantly silts and clays) are a more important influence on transparency as water flows downstream carrying and depositing sediment with it. A good example of dissolved material that affects transparency is the tea color of some northern, bog-influenced lakes and streams, which is caused by dissolved organic material.

The transparency of stream water tells us a lot about general stream quality. First, transparency is related to some key water pollutants. In general, a low transparency reading reflects a large amount of sediment (excessive soil material) or other suspended material like algae in the water. Excess soil material is a significant pollutant itself, whether it is suspended in the water column or deposited as sediment on stream bottoms. Sediment suspended in stream water reduces light penetration needed for the growth of beneficial aquatic plants. The vision of predatory fish may be limited by suspended sediment in stream water, interfering with their ability to capture prey. Soil material may also have pollutants attached to it such as phosphorous and petroleum products. These pollutants may impact flowing water directly, or be carried downstream into lakes or reservoirs where they can degrade water-quality conditions. High algae concentrations (which also lower transparency) are most likely to occur in large rivers with high nutrient concentrations at low flow.

Although algae contribute to dissolved oxygen in the river while alive through the process of photosynthesis, they deplete oxygen when they die and decompose in the bottom of the river. Sediment on stream bottoms can smother fish eggs and keep them from getting the oxygen needed to survive. Deposited sediment can also interfere with the behavior of insects that live in streams and are eaten by fish (Waters 1995).

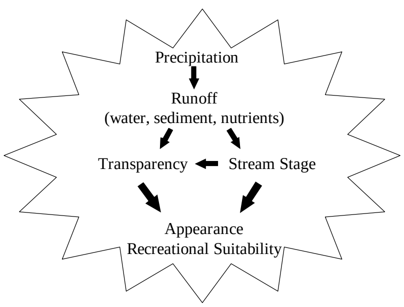
Because of these effects of excessive sediment on streams, the MPCA sets limits on the discharge of suspended solids to waters, and has "standards" for turbidity, which should not be exceeded in flowing waters. Turbidity is defined as "an optical property of water resulting in a loss of light transmission from absorption or scattering" (Dieter 1990).

Transparency is also a meaningful measure of water quality because people can relate to it, and easily understand how it reflects stream condition. A citizen once described his long-term goal for a river in these terms: "I want to be able to see my toes when I'm standing knee-deep in the water." The CSMP provides a tool that will allow citizens to track progress toward identified water-quality goals for their streams.

Precipitation and Stream Stage

Some rainfall eventually makes its way back to streams. Depending on the kind of plant life and land management nearby, rainfall can affect stream water level or "stage" by increasing the amount and rate at which water flows through stream channels. Water quality changes in response to precipitation as a result of management practices used on the surrounding land. For example, rainfall can influence stream-water transparency by carrying sediments and other materials to streams over land in runoff, or underground through urban and rural subsurface drainage systems. By recording precipitation amounts on a daily basis and simultaneously measuring stream transparency and stage, volunteers and the MPCA can begin to "tease out" the connections among these factors.

Links between CSMP measures



Appearance and Recreational Suitability

Volunteers rank water Appearance on a color scale that ranges from "crystal clear" to "green or muddy with floating scum or odor." Appearance information provides insight on the possible causes of low transparency readings. A low transparency reading in conjunction with a cloudy appearance may reflect high levels of suspended sediment in the water, whereas a green tint suggests that algae growth may be reducing water clarity. Recreational suitability rankings help us decipher connections between what people think about the quality of a stream and what they measure (e.g. precipitation and transparency measurements). Stream recreational suitability rankings range from 1-5, where 1 is "beautiful, couldn't be better", and 5 is "swimming and aesthetic enjoyment of the stream nearly impossible."

By tracking transparency and volunteer perceptions (appearance and recreational suitability) of water quality simultaneously, correlations may be identified and transparency goals set for streams. As we learn more about how transparency corresponds to other water-quality parameters such as turbidity and Total Suspended Solids, transparency and perception information may be useful in setting water-quality goals for these parameters in a given stream or region.

Recreational Suitability

1 =Very Good: Beautiful, could not be better

2 = Good: Very minor aesthetic problems; excellent for body-contact recreation (swimming, wading, etc.)

Appearance

1 = Clear - crystal clear, transparent water

2 = Milky - not quite crystal clear; cloudy white or gray

3 = Foamy - natural or from pollution

4 = Tea-colored - clear, but colored due to wetland or bog

Putting CSMP Data to Work

Data submitted by CSMP volunteers are entered into the U.S. Environmental Protection Agency's water-quality STORage and RETrieval database (STORET), along with other MPCA data. There are many stream miles in Minnesota for which the MPCA does not have water-quality information. Data from the CSMP therefore have the potential to greatly augment current stream water-quality databases, and enhance our general understanding of Minnesota stream conditions. Figure 1 shows the number of CSMP volunteers in each of Minnesota's 10 major drainage basins.

Data collected by volunteers will help identify water-quality problems, prioritize areas for additional research, and track progress toward improvement. Volunteer data may also be useful for a variety of more locally-based monitoring approaches including:

- Screening a watershed to determine which areas might be the primary source of pollution
- Long-term tracking of water quality in a particular stream
- Track seasonal water quality changes and response to precipitation (Figure 2.)
- Upstream-downstream monitoring (e.g. above and below a wetland or construction site)
- Monitoring urban runoff generated by precipitation or snowmelt.

Transparency tube Measurements: Relationships with Other Measures of Water Quality

Measurement of stream-water transparency bears many similarities to the measurement of lake transparency using the Secchi disk. As with lakes, the clarity of stream water is generally a function of the amount of suspended material (i.e., total suspended solids) and the ability of those materials to scatter light (i.e., turbidity) in the water. A discussion of the types of materials suspended in stream water and their effects on transparency follows.

Ecoregions and Stream-Water Quality

The U.S. Environmental Protection Agency has divided the continental United States into ecoregions based on soils, geomorphology, land use, and potential natural vegetation. For Minnesota, this results in seven fairly distinct ecoregions (Figure 3). For example, the Northern Lakes and Forests ecoregion (NLF) is predominately forested with numerous lakes and is located in the northeastern part of Minnesota. The Western Corn Belt Plains ecoregion (WCBP), located in the southern third of Minnesota, has rolling terrain and is extensively cultivated with row crops.
The ecoregion framework provides a good basis for evaluating differences and similarities in Minnesota's streams. Water quality data from a set of representative, minimally impacted streams was evaluated for each ecoregion (McCollor and Heiskary, 1993). These data provide a frame of reference for evaluating stream water quality in each ecoregion. A partial summary of these data are provided in Table 1.

The Nature of Suspended Materials in Minnesota Lakes and Streams

In Minnesota lakes, suspended algae is the primary material that limits light transparency and results in low Secchi transparency readings. A high correlation between Secchi transparency and algae (measured as chlorophyll-a) is evident in Figure 4. Based on data from Minnesota's ecoregion reference lakes, regional patterns in this relationship are evident as well. Chlorophyll-a concentration is relatively low and Secchi is relatively high in the lakes of the Northern Lakes and Forests and North Central Hardwood Forests. Small increases in chlorophyll-a result in large changes in transparency in these lakes. In contrast, chlorophyll-a is high and transparency is low in lakes of the Western Corn Belt Plains, where the relationship tends to level off (Figure 4).

As in streams, suspended sediments (e.g., clay particles) may also limit transparency in some lakes, especially in shallow lakes receiving high sediment loading from their watersheds. This is common in southern Minnesota lakes in the WCBP and Northern Glaciated Plains ecoregions (Figure 3). Bog-stain (tea-color), arising from incompletely decomposed organic matter from wetlands, may influence transparency as well. This is more common in lakes and streams that have extensive wetlands in their watersheds, as is common in the NLF ecoregion.

Turbidity and total suspended solids (TSS) are interrelated in Minnesota streams (Figure 5). Based on preliminary work conducted during 1997, MPCA staff identified significant relationships between transparency-tube measurements, TSS, and turbidity (Figures 6 and 7). These relationships are reflected by the high correlation coefficients (R^2) between transparency- tube readings and TSS ($R^2 = 0.75$) and turbidity ($R^2 = 0.86$). As with Secchi and chlorophyll-a, a curve-linear or "power" relationship between transparency-tube measurements and TSS and turbidity is indicated. At low levels of TSS and turbidity a relatively linear relationship is evident, and small increases result in measurable declines in transparency -- somewhat akin to the Secchi and chlorophyll-a relationship. An inflection point in the curve is noted as transparency falls below 25 to 30 centimeters. This inflection point corresponds to TSS concentrations between 30-50 mg/L, and turbidities of 20-25 Nephalometric Turbidity Units (NTUs). As transparency declines over a range from about 30 cm to 10 cm, TSS concentrations and turbidity increase dramatically, with increased variability in the relationship. As tube readings fall below 10 cm, further increases in TSS or turbidity result in minimal declines in transparency -- similar to extremely productive, algae-rich lakes (Figure 4).

One way to improve our understanding of the relationship between transparency tube readings, TSS and turbidity is to examine river-specific relationships. Figure 8 provides a comparison of these relationships between the Blue Earth River, which drains a highly agricultural watershed; and the Mississippi River, which drains a predominantly forested watershed in its upper reaches. A linear relationship is evidenced for both rivers, though the variability is much higher for the Blue Earth River (Figure 8). Turbidity values range from about 5 to 20 NTUs and transparency tube values range from 50 to 17 cm for Mississippi River sites. The regression equation for the Mississippi River ($y=-0.35x + 24.9$) has moderate slope and a high R^2 (0.70). Blue Earth River turbidities range from 22 to 78 NTUs and transparency tube values range from 25 to 8 cm. The Blue Earth River relationship also has a high R^2 (.73) but a much steeper slope ($y=-2.15x + 73.8$) and greater variability than the Mississippi River sites. This variability suggests the need to examine additional river-specific relationships where possible to increase the predictive ability of the transparency tube and understand what factors may be influencing transparency measurements, rather than relying simply on statewide relationships as depicted in Figures 6 and 7.

The significant relationships described above suggest the potential to predict stream TSS or turbidity based on transparency-tube measurements. For lakes, Secchi transparency is commonly used to estimate the "trophic status" or productivity of lakes based on regression equations developed from empirical data (Figure 4); or from equations such as Carlson's Trophic State Index (Carlson, 1977). These equations developed for lakes allow for the estimation of chlorophyll-a and total phosphorous as well. Based on the interactions among transparency, TSS and turbidity displayed in Figures 6 and 7, there is potential for defining similar relationships for streams with a focus on TSS and turbidity. Understanding the interactions among transparency, TSS, and turbidity could provide a basis for characterizing the health of a stream relative to existing water-quality standards, such as the Minnesota turbidity standard of 25 NTU; or by comparison to ecoregion “yardsticks” as compiled from minimally-impacted streams (Table 1). For example, TSS in the 2-6 mg/L range is typical for minimally impacted streams in the NLF ecoregion (Table 1), whereas TSS in the 10-60 mg/L range is typical for streams in the WCBP ecoregion. In terms of transparency, this corresponds to measures in the >60 to 45 cm range for the NLF, and 45 to 15 cm range for the WCBP ecoregions.

Conclusions and Recommendations

The CSMP provides an excellent opportunity for volunteers to learn about their local stream, while concurrently collecting valuable water quality data. This data can then be used for statewide and regional comparisons in water quality based on the significant relationships between transparency tube readings and established water quality parameters. Other uses for CSMP data include: a screening tool to identify areas of impairment, where additional monitoring and water quality improvements are needed; and observing how water quality changes seasonally and in response to precipitation.

Transparency tube readings taken by CSMP volunteers have potential for screening stream reaches for elevated TSS or turbidity readings. Frequent exceedances of pre-defined thresholds such as the Minnesota turbidity standard or ecoregion yardstick values could indicate impairment of stream water quality. This, in turn, could serve to prioritize streams for more detailed chemical, physical, or biological monitoring, and watershed investigations to determine potential sources of excess sediment or other pollutants entering a river.

Additional research is needed on relationships among transparency, turbidity and TSS at the ecoregion and watershed scales. Research at these scales will refine empirical relationships among these water quality parameters and provide insight on what influences them, such as differences in soils, land cover and land use practices. The increased variability observed in the relationship between transparency tube measurements and turbidity at low transparencies/high turbidities suggests there may be increased sampling error in transparency measurements at this range. Investigations are needed to determine if human sampling error increases in this range, and if so, what can be done to minimize this error.

The CSMP is a young program that continues to evolve. We hope that the CSMP is incorporated into environmental education curricula in Minnesota. The MPCA continues to explore new ways that CSMP data can be used in water quality assessments. Additional correlations and linkages of CSMP data to chemical and biological parameters, flow regime, rainfall-runoff, in-stream structure, and watershed characteristics will likely be identified in the future. These linkages will potentially broaden use of the transparency tube and help establish it as a simple but highly useful tool for measuring the health of a stream. Our long-term goal is to use the CSMP to empower citizens as stewards of their local river or stream.

Figure 1. Number of Citizen Stream–Monitoring Program Volunteers by Major Minnesota Drainage Basins

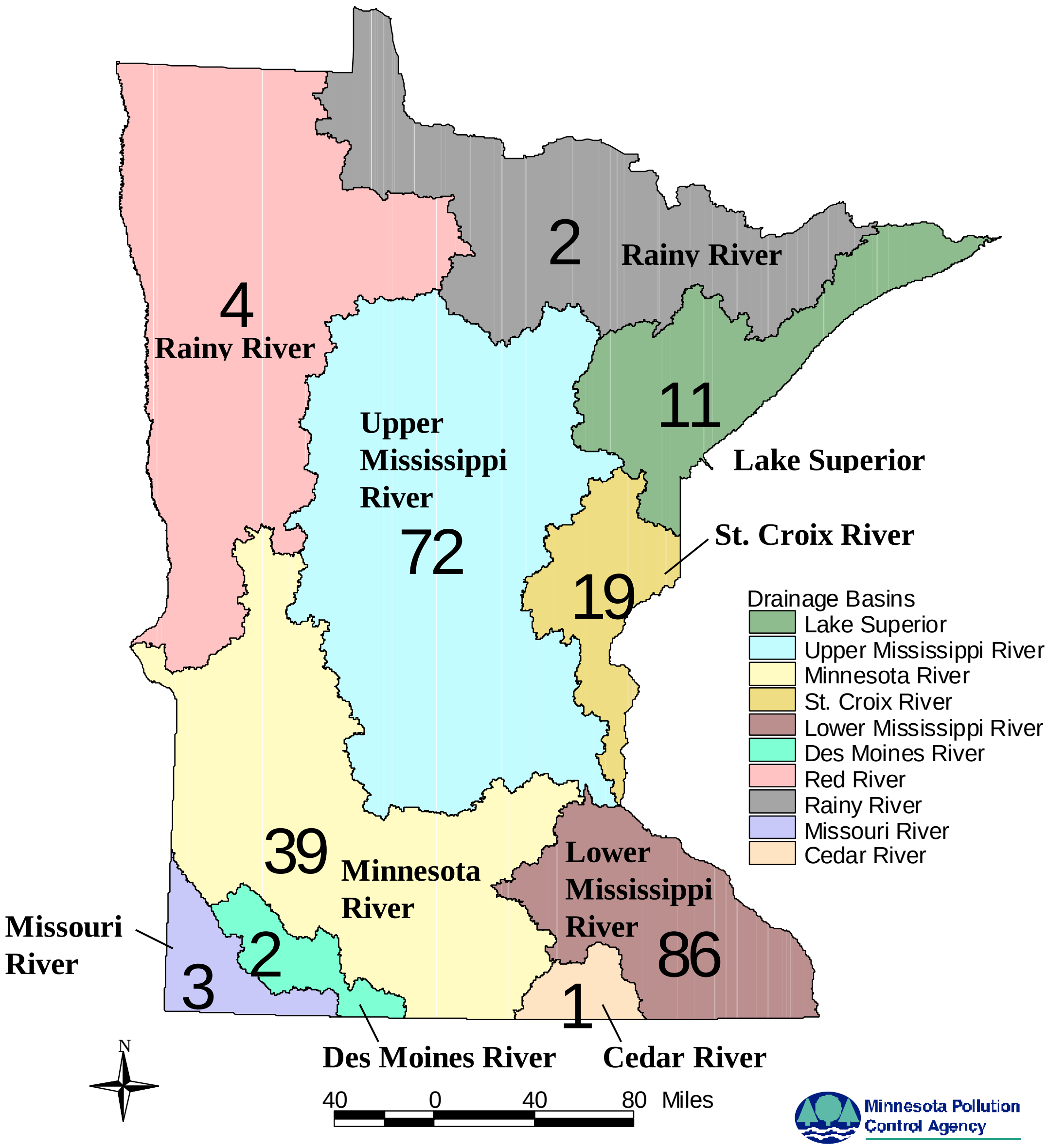
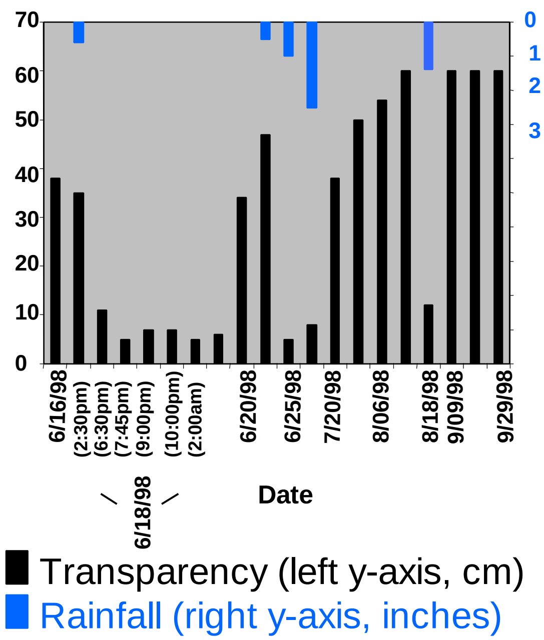


Figure 2. 1998 CSMP Data at Cannon River near Welch, MN
Volunteer: Steven Axelson



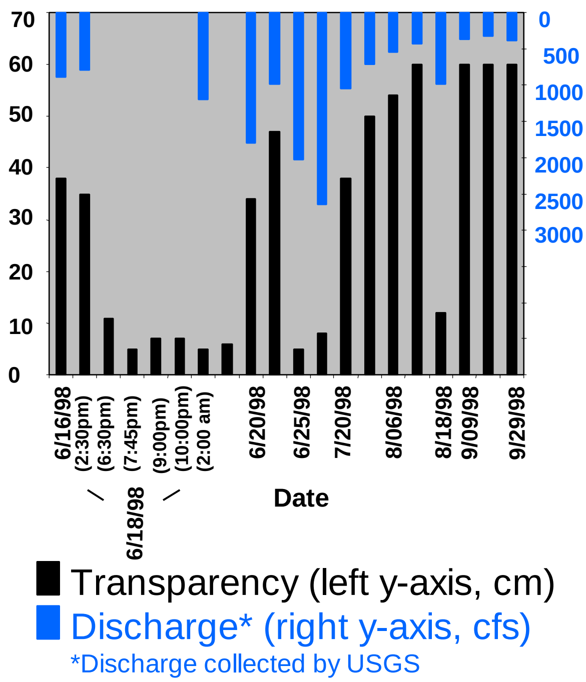


Figure 3. Minnesota's Seven Ecoregions. Mapped by USEPA.

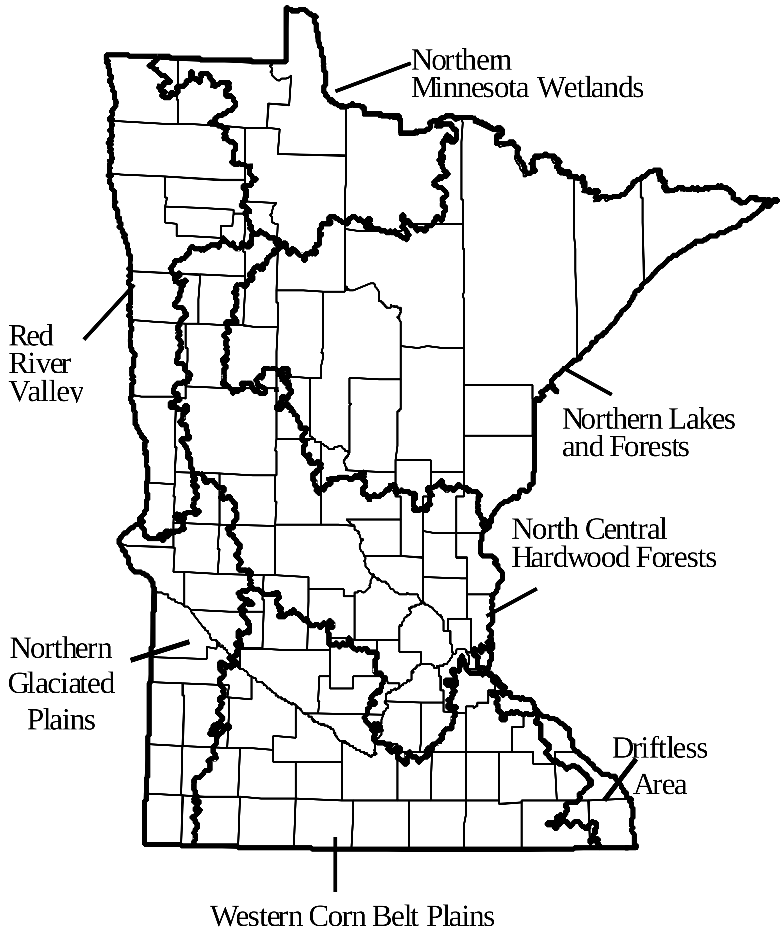


Table 1. Interquartile Range of Concentrations for Reference Streams in Minnesota by Ecoregion.[1] Distributions of annual data from 1970-1992 (McCollor and Heiskary, 1993; note 1 mg/L = 1 ppm = 1,000 ppb)

	Total Phosphorus (mg/L)			Total Suspended Solids (mg/L)			Turbidity (NTU)		
Region/ Percentile	**25%**	**50%**	**75%**	**25%**	**50%**	**75%**	**25%**	**50%**	**75%**
NLF	0.02	0.04	0.05	1.8	3.3	6.0	1.7	2.5	4.3
NMW	0.04	0.06	0.09	4.8	8.6	16.0	4.1	6.0	10.0
NCHF	0.06	0.09	0.15	4.8	8.8	16.0	3.0	5.1	8.5
NGP	0.09	0.16	0.25	11.0	34.0	63.0	5.6	15.0	23.5
RRV	0.11	0.19	0.30	11.0	28.0	59.0	6.0	12.0	23.0
WCBP	0.16	0.24	0.33	10.0	27.0	61.0	5.2	12.0	22.0

[1]Interquartile range is determined by sorting measures from lowest to highest and represents those measures between the 25th and 75th percentile.

Figure 4. Secchi Disk Transparency vs. Chlorophyll-a.
Based on summer means from ecoregion reference lakes
(NLF=Northern Lakes & Forests, NCHF=North Central Hardwoods Forests, WCBP=Western Corn Belt Plains, and NGP=Northern Glaciated Plains)

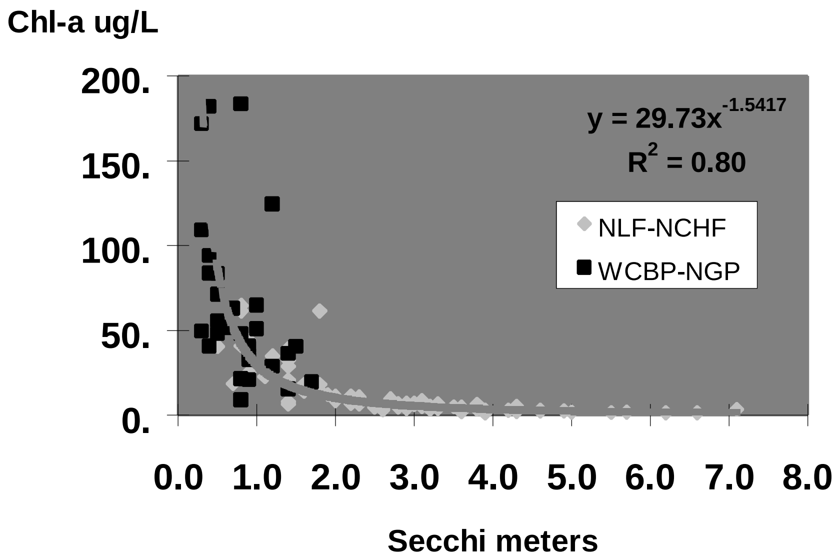


Figure 5. Turbidity vs. Total Suspended Solids for Minnesota Streams

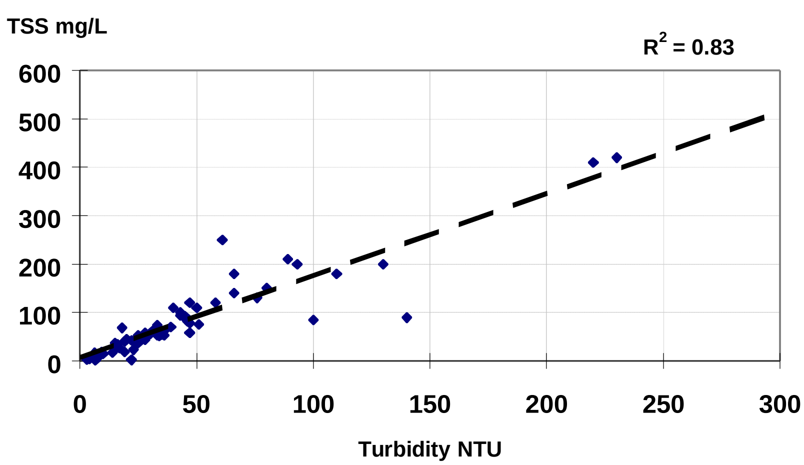


Figure 6. Transparency tube Readings vs. Total Suspended Solids.
Summer-mean data from several Minnesota streams 1995-1999 (N=312)

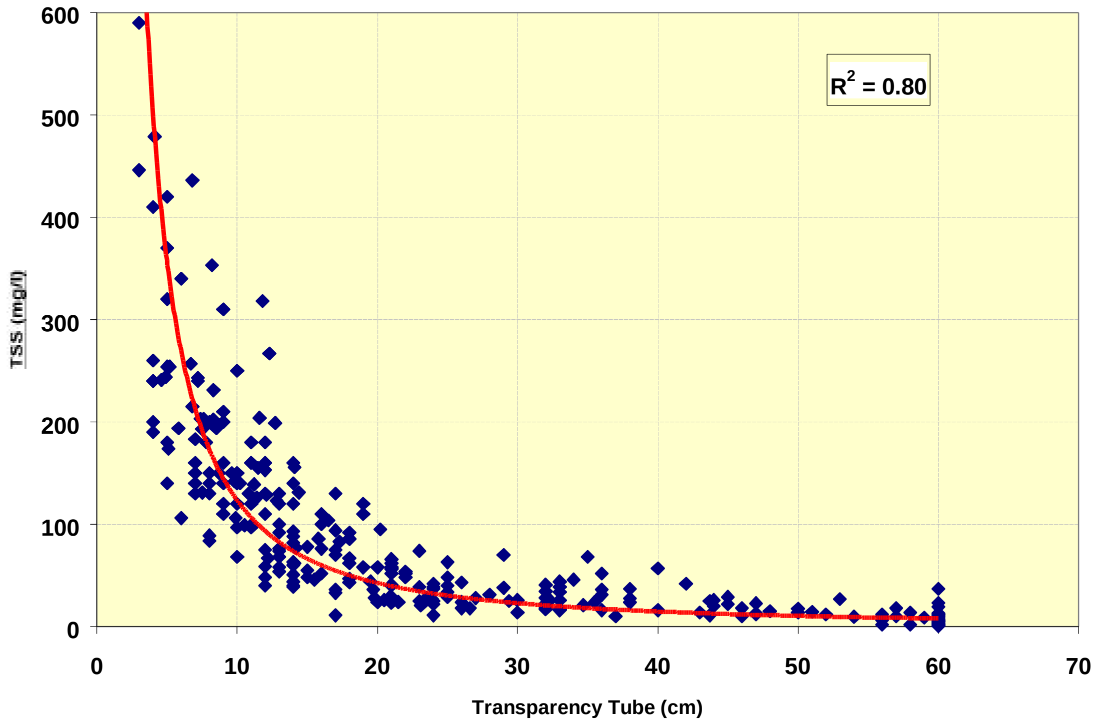


Figure 7. Transparency tube Readings vs. Turbidity
Summer-mean data from several Minnesota streams 1995-1999 (N=379)

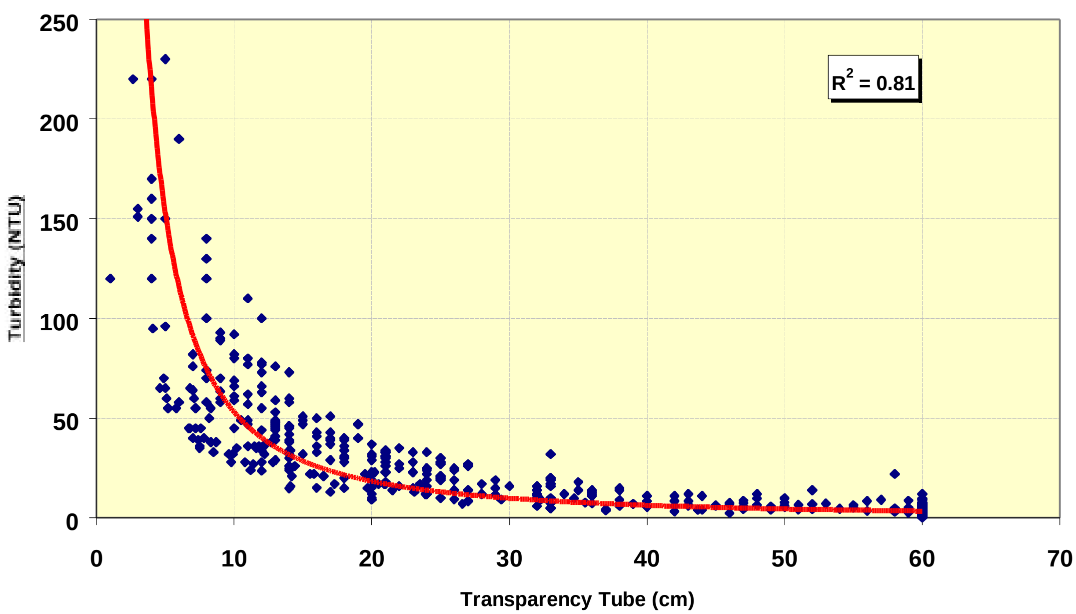


Figure 8. Mississippi & Blue Earth Rivers:
1999 Transparency Tube vs. Turbidity Data